

Pulp stress with different tooth movements in normal and open apex: 3D analysis using Finite element method

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Abstract:

Aim: Orthodontic treatment outcomes are combination of advantages and disadvantage. The force implied during treatment could affect dental pulp status. Amount of changes in pulp complex depend on the types of tooth movements and whether the apex is open or not. The aim of this study is to compare the effects of different orthodontic tooth movements in two kinds of open and normal apices by 3D Finite element analysis.

Materials and Methods: Two three-dimensional Finite element models of an upper central incisor were modeled based on average dimensions. The models contained cortical and spongy bone, uniform thickness PDL of 0.25 mm and an upper central incisor. The differences between the models was the apex development which was complete in the first model and open in the second one in Solid- works 2006 and transferred to ANSYS Workbench Ver. 11.0. Different force systems to produce tipping, bodily and intrusion were applied in the tooth crown. The Von Mises stress was assessed along two defined paths.

Results: Maximum amount of the stress along the long axis of pulp belonged to open apex by tipping movement then intrusion with normal apex and finally bodily movement in open apex samples. In evaluation as regard of stress along apical third of PDL the highest stress created by intrusion in normal apex group

Conclusion: In open apex, tipping and bodily movement could induce much more stress and in normal apex the concern of root resorption by intrusion was more than other types of tooth movements.

Keywords: Dental pulp, Tooth Movement, Stress, Finite Element Method
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Achieving major advancements in various fields of orthodontic make it necessary to concern more on dental structure health condition. Ideal treatment is to reach perfect occlusion while maintaining healthy condition of tooth and surrounding tissues. Dental pulp is a special environment and preservation of its normal condition has major role in orthodontic treatment outcome. Many studies documented degrees of root resorption in orthodontic patients.¹⁻³

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Several studies showed pulpal reaction and resorption lacunae on the roots were created by orthodontic force.⁴⁻⁷ Among different types of tooth movements, intrusion is the most probable one to induce root resorption while other types of movements such as bodily or tipping can also predispose to root resorption.⁸⁻⁹ The prerequisite sequences to tooth movement are the alteration of blood flow, inflammatory reaction and cellular changes.¹⁰⁻¹² These sequences could shift the condition to unpleasant as regard of tissue health status. One of the main parameters that influence the pulp health is the blood flow change which is an important event in pulp. The pulp is covered by rigid shell and circulation can be performed only through the apical foramen. According to this condition, alteration of blood flow can have serious influence on dental pulp

health. In this regard orthodontic tooth movement can change blood circulation that eventually has been implicated in dental pulp.¹³ The more stress on apical pulp area, the less blood circulation can be expected. Several studies have shown that vascular changes as response of orthodontic force which can lead to pulpal reaction.¹⁴ Mostafa showed severe degeneration of odontoblasts in application of extrusive force related to changes in blood supply.¹⁵ Similar results were reported by Stevic by applying intrusive forces.⁸ McDonald stated that blood flow in dental pulp decreased when tipping force was applied.⁷ Various studies evaluated the dental pulp changes during orthodontic tooth movements in different point of view.¹⁶⁻¹⁸ Many studies are based on cellular or chemical changes in dental pulp tissue^{4-6,8,10} but there is relatively few studies to consider the stress which is produced by different orthodontic movements such as intrusion, tipping and bodily movement.¹⁹⁻²⁰ The aim of this study is to analyze orthodontic tooth movements by the Finite element method (FEM) and evaluation of stress changes in radicular pulp extending from apex to cervical area of the tooth and apical third PDL area from labial to palatal.

Materials and Methods:

Two FEM models of an upper central incisor were designed. Each 3D model contained cortical bone, spongy bone, PDL, and the teeth. An average sized upper central incisor was considered for the first model.²¹ The only difference between 3D models was in the anatomy of their root apex. At the first model, the root apex was complete and in the second model (group A), the root apex was not developed and was considered as open (group B). PDL was assumed to be 0.25 mm all around the root. SolidWorks 2006 (Concord, Massachusetts, USA) was selected for the modeling phase. The models were transferred for calculation to the ANSYS Workbench Ver. 11.0 (ANSYS Inc. Soutpointe, , Cononsburg PA , USA). Material properties were applied

based on recent researches. (Table 1) Models were meshed, between 154330 nodes and 159965 elements were used in these models. (Figure 1) All nodes at the base of the models were restrained so that all rigid body motions were prevented. 0.5 N force was applied for tipping and intrusion and also for bodily movement with needed moment. Von Mises stress was evaluated along a path of nodes along the long axis of the pulp and the other path starting at the apical third on the palatal area of the PDL moving towards the apex and continuing to the apical third on the labial side.

Table I. Mechanical properties of the materials used in the models.

	Young's modulus (MPa)	Poisson's ratio
Tooth	20300	0.26
PDL	0.667	0.49
Spongy bone	13400	0.38
Cortical bone	34000	0.26

Results:

Amount of stress along the pulp long axis
The result of analysis showed that in the normal apex size (group A), maximum amount of stress located in apical constriction. (Figure 2) This was true in intrusion, tipping and bodily movement types (Figure2).

The maximum stress was 0.0000822 MPa in bodily movement and 0.000138 MPa in tipping but intrusion induced much more stress (0.000379 MPa) than others types of movement. Stress reduced rapidly beyond apical constriction in all three movements.

In open apex (group B) the condition was different and maximum amount of stress in tipping movement was 0.000888MPa in apical constriction which was much more than maximum stress in bodily movement (0.000137 MPa) and intrusion (0.0000888 MPa). Intrusion did not impose so much stress on root in comparison with other two types of movements and there was not significant different in the amount of stress considering location. (Figure 3)

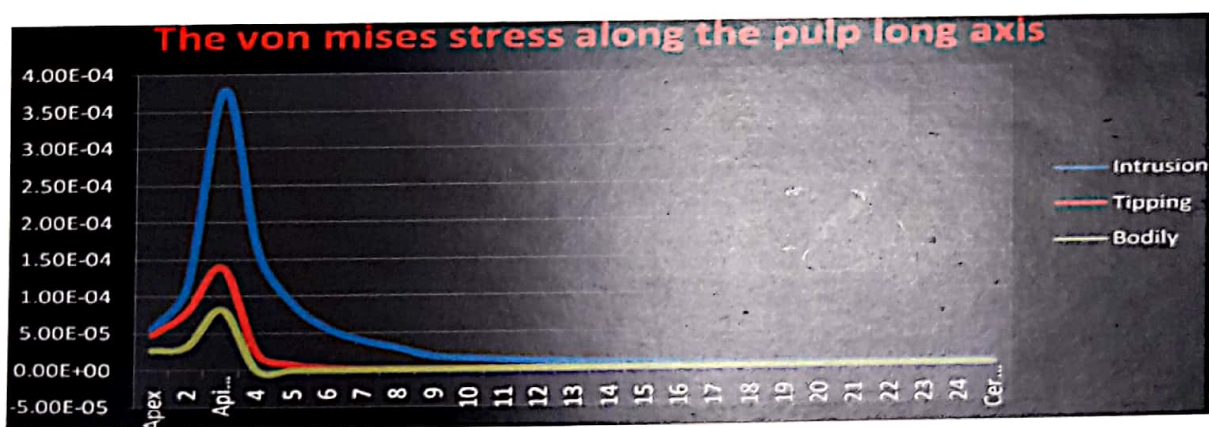


Figure 2:The Von Mises stress along the pulp long axis in different types of tooth movements in normal apex samples.

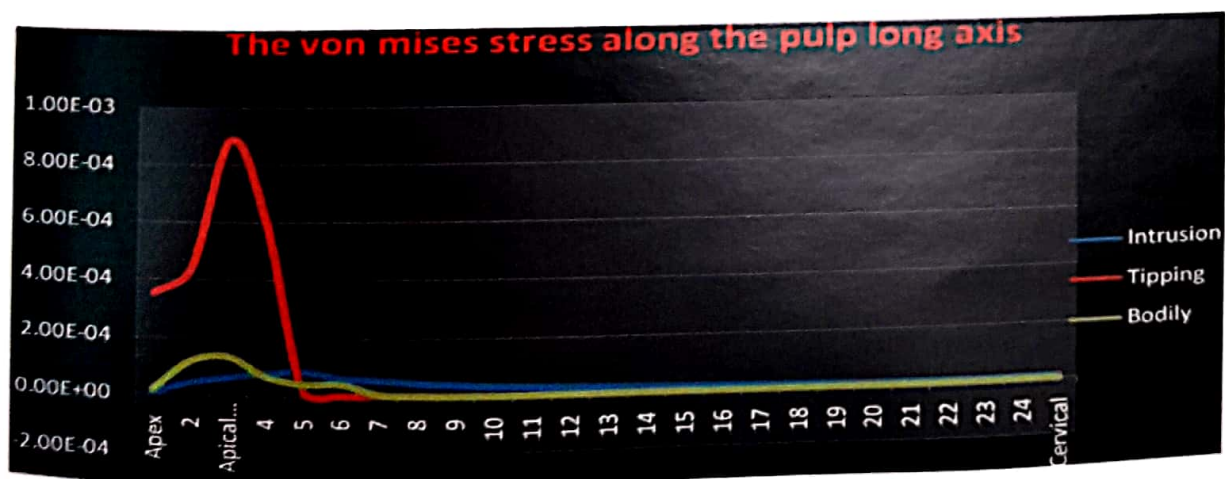


Figure 3: The Von Mises stress along the pulp long axis in different types of tooth movements in open apex samples.

Comparing normal apex size (group A) and open apex (Group B) as regard of intrusion the results revealed that in two groups the maximum stress was in the apical constriction that was (0.0000888 MPa) in normal size apex and (0.000379 MPa) in open apex group. In both groups, stress decreased continuously from apical to cervical. (Figure 4)

In Contrast by intrusion, the maximum stress in tipping movement was seen in open apex that was 0.000888 MPa which was much more than normal apex that was 0.000138 MPa. The maximum stress in both groups was in apical constriction. (Figure 5)

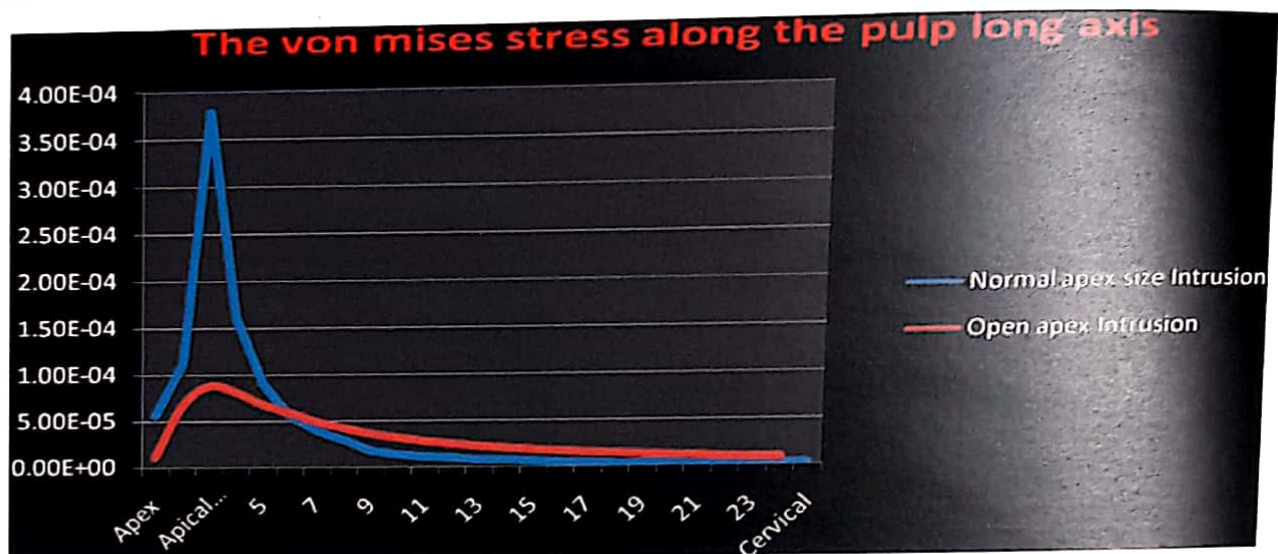


Figure 4: The Von Mises stress along the pulp long axis by intrusion in normal and open apex samples.

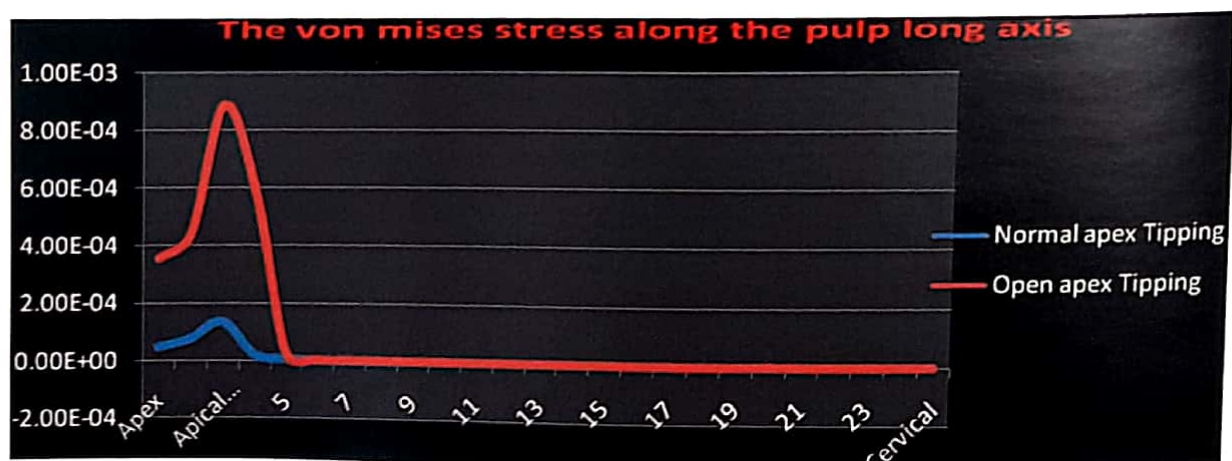


Figure 5: The Von Mises stress along the pulp long axis by tipping in normal and open apex samples.

In bodily movement the results were almost in accordance with tipping in comparing open and normal size apex. The maximum stress in open apex was 0.000137 MPa and more than normal apex that was 0.0000822 MPa. In both groups, maximum stress located in apical constriction. (Figure 6)

Considering the amount of stress along the apical third of the PDL that extended from labial to palatal in different tooth movement in normal size apex (group A) and open apex (group B) these results were achieved:

In normal apex (group A) the maximum finding in all three groups (tipping, bodily, intrusion) located in center of apex and the most of stress was in tipping 0.0000494 MPa then in intrusion 0.0000363 and finally in bodily movement that was 0.0000237 MPa. (Figure 7)

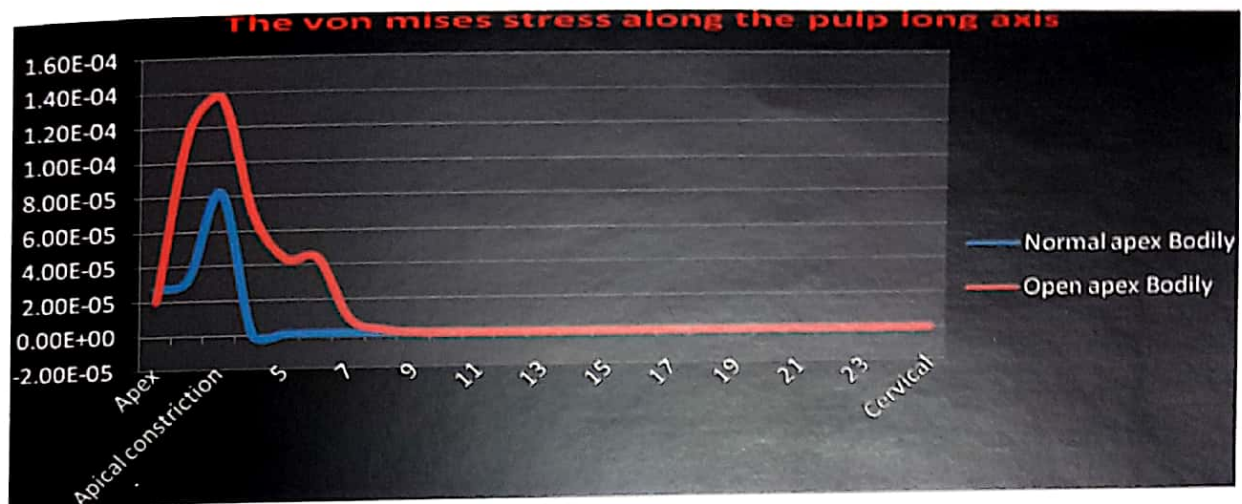


Figure 6: The Von Mises stress along the pulp long axis by bodily movement in normal and open apex samples.

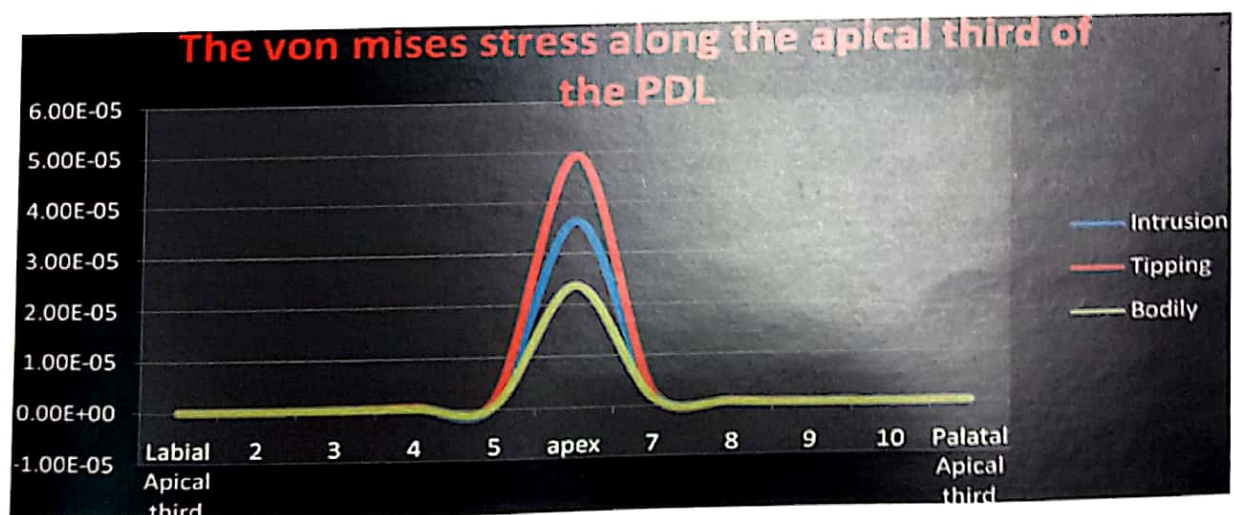


Figure 7: The Von Mises stress along the apical third of PDL in different types of tooth movements in normal apex samples.

In open apex C group B, the results were more complicated and anaximnm amount of stress were seen in tipping movement that was 0.0000690 MPa in the seventh section of palatal segment which was more than center of apex. Bodily movement induced stress that almost even in palatal segment of third of apex that was about 0.00003 MPa . The least amount of stress was in intrusion (0.0000214 MPa) that located in the fifth of labial segment of apical. The amount of stress was lower in palatal segment.(Figure 8)

By intrusion the maximum stress was in normal group (0.0000363 MPa) that was located in center of apex while amount of maximum stress in open apex group was 0.0000214 MPa , located in the fifth section of labial segment of apical third.(Figure 9).

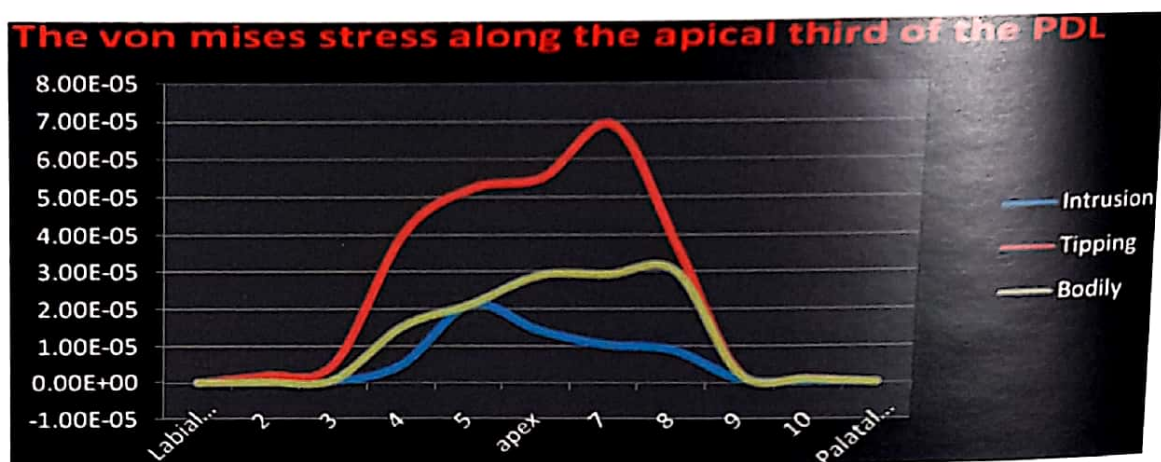


Figure 8: The Von Mises stress along the apical third of PDL in different types of tooth movements in open apex samples.

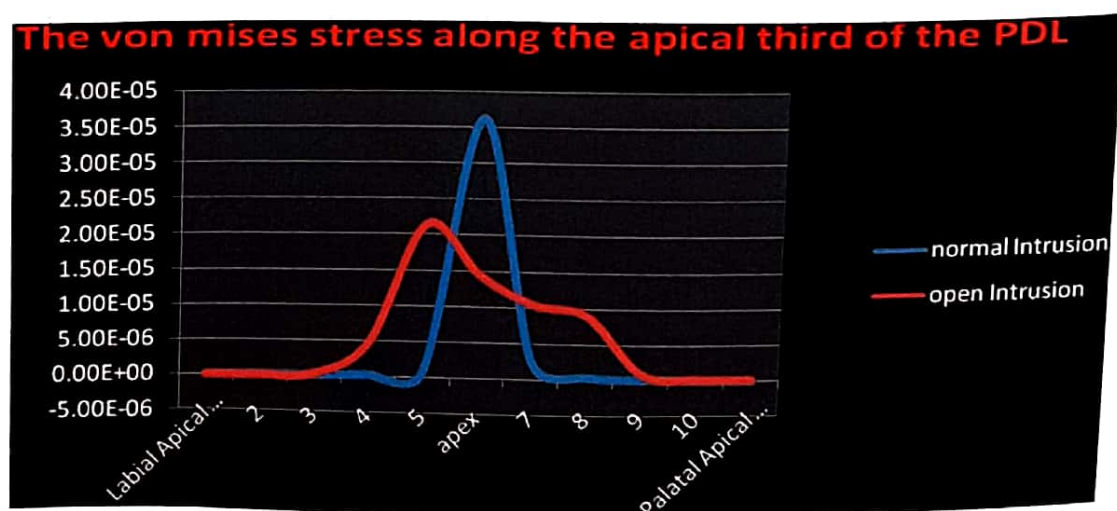


Figure 9: The Von Mises stress along the apical third of PDL by intrusion in normal and open apex samples.

Interesting results were achieved in bodily movement between two groups. There were two peaks in open apex samples which were located in apex and eighth section of palatal segment of apical third (0.00003 MPa). On the other hand, in normal size apex (group B) there was one peak that decreased rapidly. In this group maximum stress was located in center of the apex (0.0000237 MPa). (Figure 10)

Finally the result of tipping movement in two groups represented that in normal apex (group A) maximum amount of stress was in the center of the apex (0.0000494 MPa) that was more than other labial and palatal segments. In group B, the situation was different. From labial side to the center of resistance, there was an increment in the amount of stress until to the center of the apex. From the center of the apex to the palatal side the increment continuous and maximum amount of stress was seen in seventh segment of palatal side (0.000069 MPa) followed by a rapid decrease. (Figure 11)

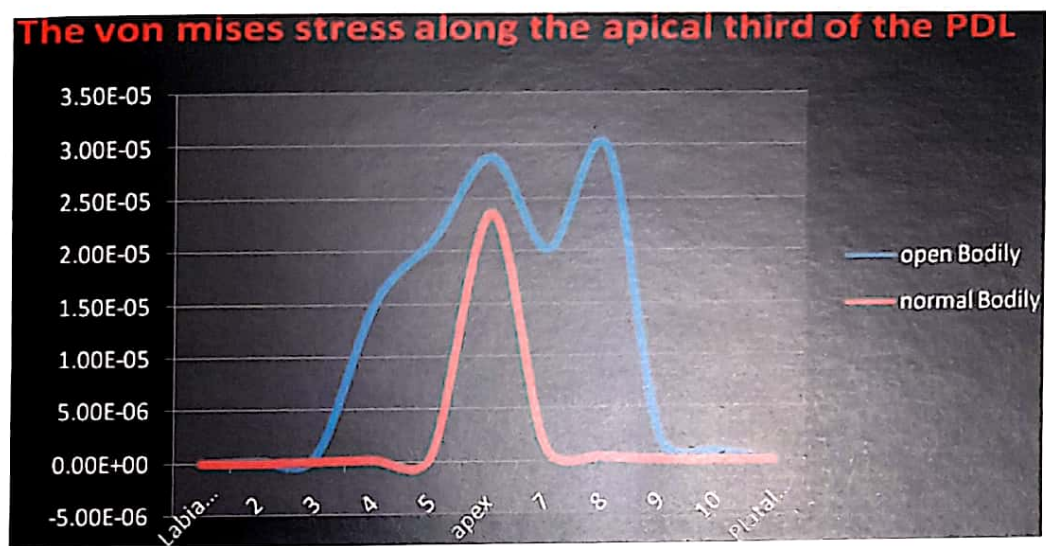


Figure 10: The Von Mises stress along the apical third of PDL by bodily movement in normal and open apex samples.

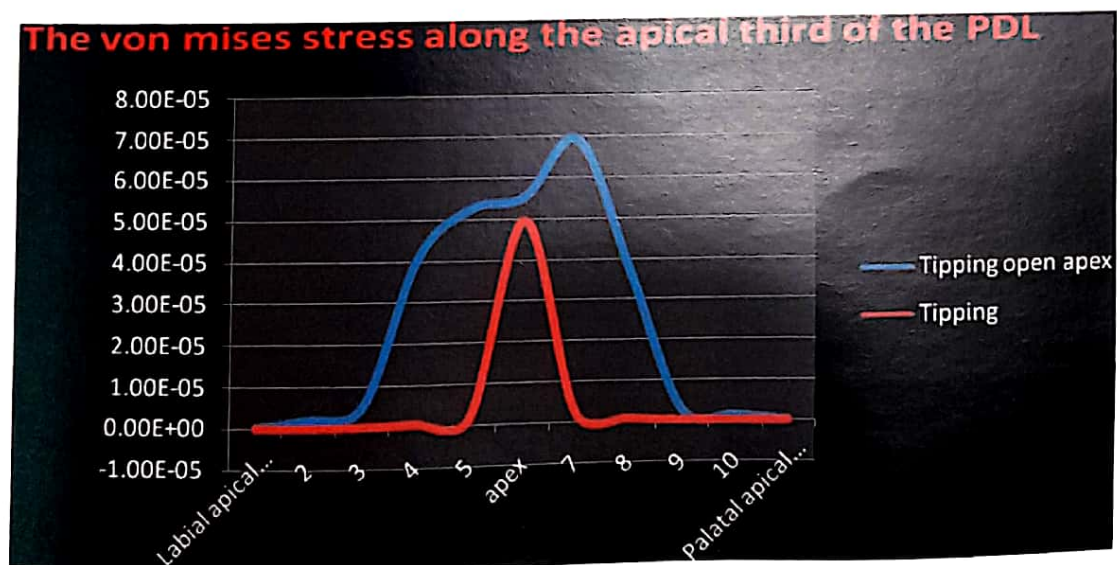


Figure 11: The Von Mises stress along the apical third of PDL by bodily movement in normal and open apex samples.

Discussion:

The result of study revealed that in roots with normal apices there was not so difference as regard of stress amount in different types of tooth movements except for intrusion. So intrusion should be done with considering the risk of root resorption which is in accordance with previous studies.²⁰⁻²³⁻²⁴ In open apex roots, tipping is not considered as a safe type of tooth movement because of its higher induction of stress that leads root resorption. Removable appliances that widely used in mixed and early permanent dentition that tip the teeth need caution in force application. It is not wise to tip the teeth with open apices if it is possible to delay the treatment until normal apex roots development. Considering intrusion, open apex roots were more resistance than normal one in root resorption that confirmed by Mavragani.²⁴ The results of this study showed that the amount of stress in open apex is lower than normal apex roots by intrusion. Therefore the older patient, the much more root sorption will happen by intrusion. Bodily movement is one of the most useful types of tooth movement in orthodontic treatment. Based on results of this study it is better starting bodily movement after maturation of the roots of the teeth and achieving normal apex root because the amount of stress in open apex roots was more than normal apex by inducing bodily movement. By this study the maximum stress was seen in tipping movement in both groups that was located in palatal segment of the tooth. By comparing amount of stress between two groups in intrusion it would be better to intrude the teeth as soon as possible.

Conclusion:

- 1 The maximum amount of stress in normal apex roots could be induced by intrusion in both axes of labio palatal and long axes of the root.
- 2 Maximum amount of stress in open apex cases would happen by tipping movement.
- 3 The side effects of tipping and bodily movements are much more in the open apex roots than normal one.

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